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Translation

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Management and maintenance principles for existing tunnels

Principes de gestion et de maintenance des tunnels existants

Grundsätze für die Verwaltung und Instandhaltung bestehender Eisenbahntunnel



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Summary

UIC Leaflet 779-10 is addressed to all the people involved in the maintenance of underground structures and the operation of the line. Thus, the owner, the person in charge of maintenance, the designer, and the person in charge of the railway operation will find in this document the basic information they need to guarantee the satisfactory operation in the long term of a tunnel or a number of tunnels.

This leaflet gives the information that it is essential to have or know on a tunnel designed for railway trains in order to ensure the long term safety or to modify the operating characteristics. It describes the procedure to be accomplished and the steps to be followed to ensure the consistency between the different phases: assessment - diagnosis - treatment (work or other activities).

1 - General

1.1 - Fundamental definitions

What is a **tunnel** ?

- A tunnel is an underground gallery, which is excavated by human beings, in order to provide a line of communication.

NB : in a wider sense, the term "tunnel" used in the leaflet also includes the structures which are built open to the sky after cutting and then filling by the cut and cover method.
In a wider sense the whole structure forms a "subway" in the field of underground structures.

What is the **maintenance** ?

- Maintenance is a set of operations which allows a complex system to be kept in a normal state or to be restored to its specified characteristics again.

NB : Operations, which consist in modifying the specified functions, i.e. principally, in improving the performance of a tunnel are often included in the generic term of "maintenance". In this Leaflet these operations have been dealt with in a separate point (see point 4 - page 35).

What is a **diagnosis** ?

- A diagnosis is the judgement made, for a structure, after the analyse of the different assessments carried out in situ (inspections, investigations) and the theoretical forecast of how the condition will evolve, which is deduced from calculations.

1.2 - Object of the leaflet

This Leaflet is addressed to all the people involved in the maintenance of underground structures and the operation of the line.

That is to say, the owner, the person in charge of the maintenance, the designer, the person in charge of the operation will find in the document the basic information required to guarantee the satisfactory operation over time of a tunnel or a number of tunnels.

Success criteria

The purpose of this leaflet is to describe the sequence of all the operations necessary for the maintenance or the improvement of the performance of a tunnel (i.e. both to maintain it in its serviceable state and to increase its functionality) while ensuring maximum safety.

The main problems are as follows :

- it is difficult to forecast the behaviour of the ground and its future changes, in particular when it is subjected to a hydraulic gradient,
- it is difficult to know the state of the non visible part of the structure and of the ground,
- It is difficult to get access, because of the specific characteristics of the structure (access only possible by a portal) and their operating conditions.

Good maintenance, in a wider sense, involves using all the parameters and their respective impacts: technical of course, but also strategic and socio-economic.

Consequently, it is necessary that all the people involved in the sequence have the necessary capacity and competence to deal with the complex environment of a tunnel.

The object of this document is to give them all the necessary information.

1.3 - Content of the leaflet

This leaflet gives the essential information that must be known or available on an underground structure designed for railway traffic in order to ensure its maintenance over time or to modify its operating characteristics.

It describes the procedure to be achieved and the stages to be followed in order to ensure the consistency between the different stages: assessment - diagnosis - action (work or other intervention).

1.4 - Functioning and constitution of a tunnel

1.4.1 - Interaction ground-structure

1.4.1.1 - Description

The digging of a tunnel in any type of mountain (rock, powder or cohesive ground, etc.) disturbs the functioning of the latter and causes a redistribution of the internal stresses existing in the mountain. This redistribution depends on the method of digging the tunnel, on the props, on the reinforcement and lining (of all types) as introduced provisionally or definitely as well the nature of the devices (anchorings, boltings) installed if this is necessary.

Moreover, the digging of a tunnel modifies the flow of the underground water percolating through the mountain. Generally, the tunnel will act as a drain as far as this underground water is concerned. The resulting hydraulic gradients can have consequences on the characteristics of the surrounding ground and on the tunnel lining.

The knowledge of these interactions allows the evolution of a tunnel over time to be followed and the importance of these facts assessed during inspections and measurements.

The knowledge of the environment of a tunnel and all its modifications over time due to all possible causes is then a fundamental element in the tunnel maintenance.

1.4.1.2 - Elements involved in the interaction

The parameters which have an influence on the life and therefore the behaviour of a tunnel are numerous and various; some of them (not necessary in the order of importance) are mentioned below.

- *Parameters concerning the surrounding ground*
 - Grounds (rocks or soils): granulometry, strength, permeability, etc.
 - Cracking, formation fracturing, faults, joints,
 - Dihedrons,
 - Water: static underground water, flows, gradient, etc.
 - Karts, settling, etc.
 - Bolting.
- *Parameters concerning the interface structure / ground*
 - Rubble masonry,
 - Void,
 - Injection,
 - Flat coating of sealing,
 - Zone of decompressed ground,
 - Anchorings.
- *Parameters concerning the structure*
 - Lining: stones, bricks, mortar, concrete, concrete blocks, etc.
 - Invert-floor: rubble stones, concrete blocks, cast concrete, bricks, mortar, etc.
 - Elements of drainage and sealing: weep holes, flat coatings of sealing, central drain, gutter, drainage channels, etc.
 - Additional structures: brick arches, centerings, shells in shotcrete, reinforcements, anchorings, bolting, sewing, etc.
- *Parameters related to the external elements and actions*
 - Tectonic (residual tectonic stresses, land slide),
 - External loadings (fillings, construction, housing, etc.),
 - Train services (vibrations, air circulation, etc.),
 - Variation of the water level (flood, water decrease, underground water, etc.),
 - Seismology.

1.4.2 - Short description - Principal component parts of a tunnel

The major geometrical characteristic of a tunnel is that it has a great length compared with its transversal dimension, as well as limited accessibility at its ends into the open air, which are called heads.

The existing tunnels can be more than a century old as the oldest date from the first quarter of the 19th century.

The methods of construction vary depending on the nature of the ground encountered, the evolution of technology and the regulations. Therefore a great diversity of profiles can be encountered.

The characteristics of the surrounding ground lead to two major tunnel categories:

- Non-lined tunnels

These are structures for which the mechanical characteristics of the surrounding ground when the tunnel was built were such that it was not necessary to construct a lining against the surrounding ground.

- Lined tunnels

These are structures, which, during construction or at the time of maintenance operations, received a lining in the roof, in the side walls and sometimes in the floor.

Two important families can be distinguished in relation to the original operation of the lines:

- the structures for single track,
- the structure for double track.

It is rare to find tunnels with more than two tracks.

Two families can also be distinguished in relation to the traction method: electrified or non-electrified tracks.

To draw up a catalogue of the tunnels, it is necessary to:

- give them a name (inauguration name),
- locate them with respect to the origin of the line (kilometric point of entry),
- measure them (length); The reference book of each railway must state the distance between chosen points like entry and exit of the structure (right and left side wall, track axis, etc.) for the interior inspections.

This information can be registered on a panel displayed at the tunnel.

Concerning the interior marking, it is wise to fit plates, for example, every 10 metres, in order to be able to locate defects more closely.

Fig. 1 and 2 - page 6 give the principal names and the locations in a cross section.

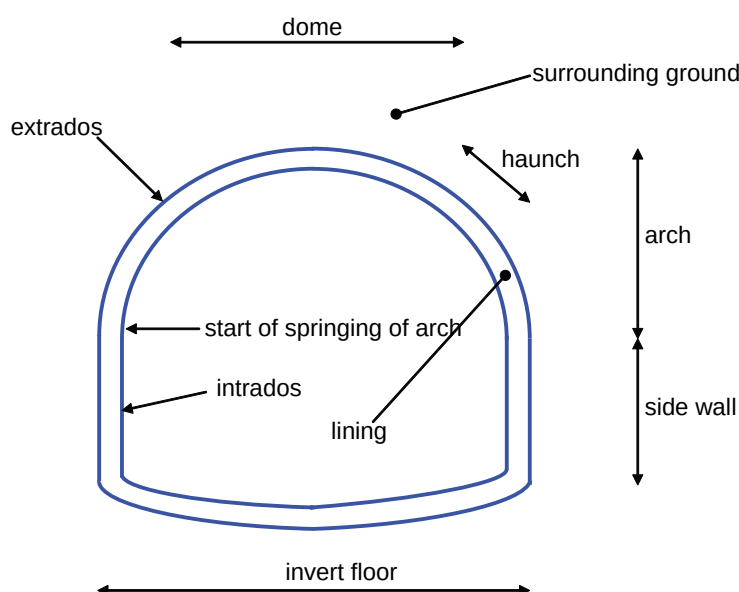


Fig. 1 - Transverse cross section

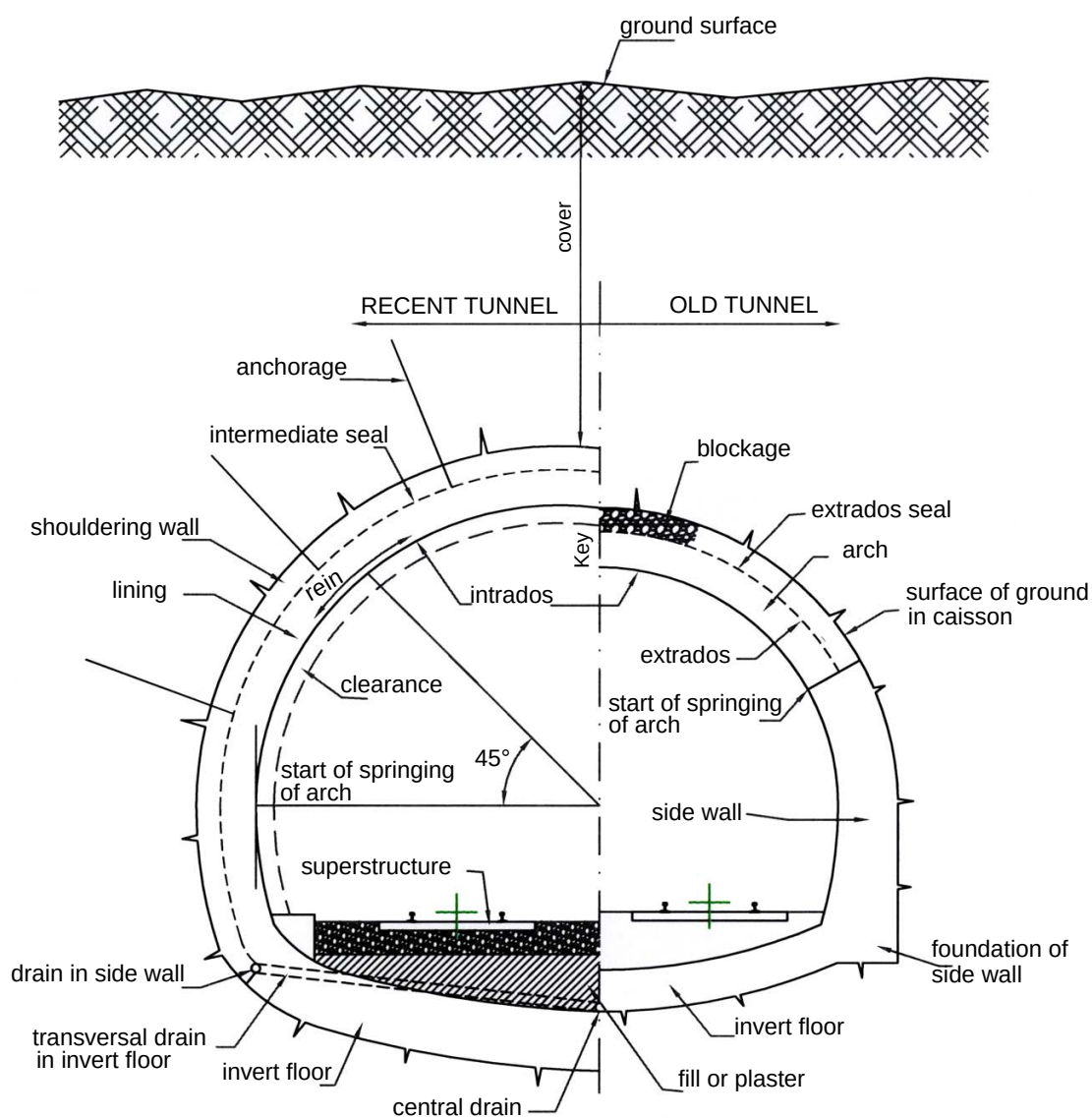


Fig. 2 - Designation of the different parts of the cross section of a tunnel

2 - Tunnel management

2.1 - General principles

Tunnels disorders very often arise from an association of problems, and only rarely from just one of them. These problems could accumulate and interact over time, slowly worsening a situation that repairs could not succeed in improving. It is thus important not to interpret the problems separately, but to compare them within the framework of several hypothetical systems taking into account all the parameters (some of them are not known with precision; therefore it is necessary to make assumptions with regard to them through ranges of realistic values).

If clearly identified problems emerge, it would be appropriate to prioritise their gravity and to evaluate the consequences.

The principal risks which can be identified are:

- structural risks related to the actual state of the tunnels,
- economic risks related to the company strategy concerning the financial resources allocated for maintenance,
- human risks related to the chances of an accident with the structure.

The analysis consists in knowing as well as possible the state of a structure and making a diagnosis, i.e. by investigating it, by measuring it, by evaluating it, but also in foreseeing the consequences of its ageing in the longer term in order to take the best decision: either to do nothing, to modify the monitoring actions or to carry out some work.

In this specialist procedure, one should, in particular, not forget the concept of responsibility; i.e. the legal constraints which could be exerted on all the people involved from the owner to the persons who do the work and the project designer, if damage occurred before, during or after the rehabilitation of the structure.

In this context, where many people are involved, the responsibilities of each have to be clearly defined and limited; this has to be done through the signature of a manager at each level.

The maintenance strategy combines the technical criteria related to the use (safety, availability) and the economic criteria: is it necessary to carry out preventive maintenance and to undertake minor work before the degradations are too important, or is it better to carry out a major repair, when the problems become unacceptable?

The theoretical approach to the phenomena by modelling in particular makes it possible to guide the observations.

The choices remain difficult in spite of the continual development of tools that help decision making. For this reason the presence of specialists, on all the levels, is essential.

2.2 - Lifespan

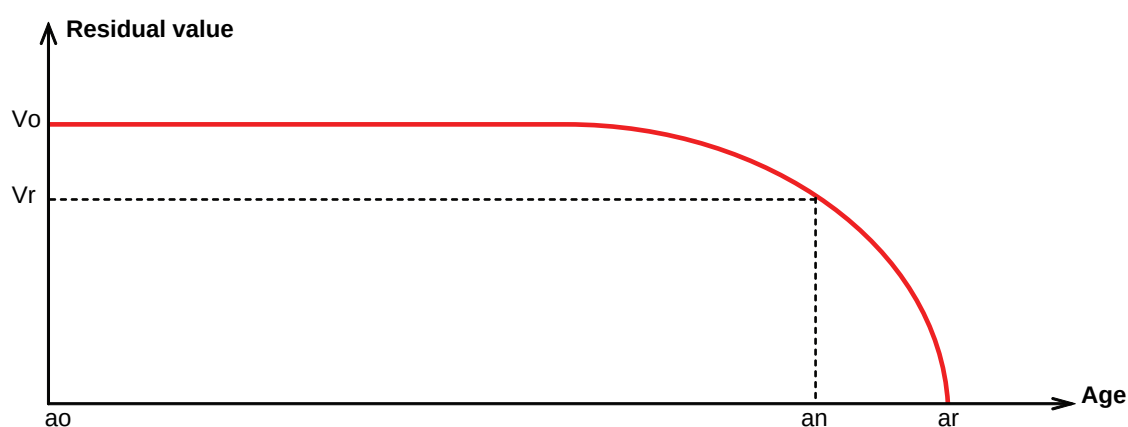
The existing tunnels were constructed for a lifespan of about hundred years. Many of them have now exceeded this term by a long way.

It is generally assumed that a good repair job is designed to last for at least thirty years.

A realistic approach to the life expectancy coupled with the costs of the work to be done consists of determining the optimum moment when work will have to be undertaken.

The work needs to be done depending on the actual state of the structure, the diagnosis and the strategy of the Infrastructure Manager concerned.

Fig. 3 gives the evolution curve of the value of a structure according to its age.



■ Desired life after the construction of the structure

ao taken into service

an age of the structure

ar collapse of the structure

Vo value of the structure when new

Vr value of the structure at age n

Fig. 3 - Shape of the value of a structure plotted against its age

2.3 - Life cycle cost

The total cost of the life cycle of a structure is the sum of the construction cost and of the costs of the successive maintenance operations (monitoring, maintenance, repair, etc.) that its state requires.

Tunnels have logistic costs and costs due to the railway operation that are much higher than those of the other structures. These costs need to be taken into account in the global cost of the life cycle.

Fig. 4 gives an idea of these differences.

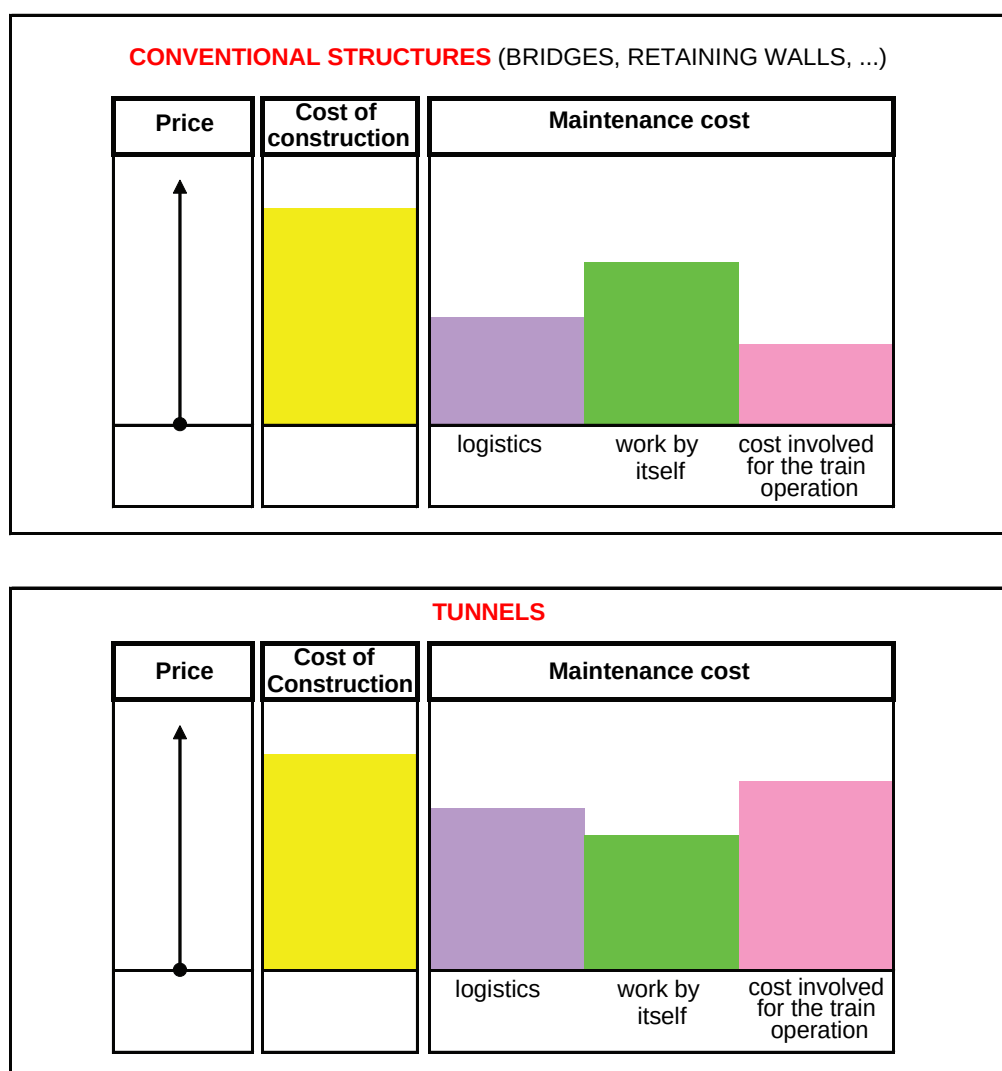


Fig. 4 - Comparative diagram of the cost of the life cycle of the structures

2.4 - Design of a maintenance operation

2.4.1 - Design of a programme

The programme is composed of two essential parts: the preventive part and the repair part. It is the repair part that was carried out in tunnels in the past. The preventive part is just beginning; it is recommended that it be greatly extended.

All the economic analysis carried out in the past on important collections of structures have shown that there is a financial as well as a technical interest (global costs, more limited maintenance operations and repair work, better control of the deadlines and less interference with railway operation) in such a preventive strategy.

In the case of tunnels, the consequences of ageing are the determining factors to be taken into account when deciding the preventive part and the repair part and when defining the content of each. This leads to the structures that are at risk being prioritised and dealt with.

It is recommended that the following tools which offer a clear vision on the choices to be made should be available:

- inventory of the damage and of its associated disorders,
- description of proposed investigations,
- different approaches for the behaviour and the design by the calculation,
- inventory of the possible work.

The conditions of success are:

- to have good files of structures,
- to be able to rely on competent and trained staff,
- to be able to make the inspections sufficiently in advance,
- to provide the studies within timescales compatible with the carrying out of the programme,
- to have resources that are adequate to carry out the preceding subparagraphs.

All these considerations make it possible to define the work to be carried out. Among this work, should be mentioned:

- The work of current maintenance: this corresponds to essential, but limited operations. These operations carried out regularly on a preventive basis in close connection with the continuous monitoring must make it possible to delay the date of work of greater importance, while maintaining a normal serviceability state. This work, in general, requires few resources and technical expertise.
- Work aiming, at least, to maintain or to restore the bearing capacities of the linings.
- Work that is done to cure irreversible problems, which can involve the collapse of the structure.

In these two last cases, a very forward looking programme should be planned.

If the state of the structure requires it, the maintenance work should be associated with the improvement work.

This work requires the same preliminary registration with respect to the operation and is subjected to the same considerations concerning safety and quality control as the maintenance work.

2.4.2 - Preparation of the operation

The diagnosis concerning the structure must be made systematically. The technical choices to be made are not independent of the costs which they imply. Preliminary studies are then often necessary.

Some possible solutions are identified including the possibility of doing nothing.

For each solution the following elements need to be evaluated:

- the scope and the duration of the work,
- the disturbance to railway operation,
- the "latest" date by which the work should be done,
- the socio-economic impact resulting from the postponing of the work (risk of unexpected interruption of traffic, etc.),
- the socio-economic impact during the duration of the work,
- the schedule and the amount of postponed work.

A socio-economic comparison of the different solutions is necessary.

This comparison must enable the Infrastructure Manager to take a decision concerning the repair of the structure or the improvement of its functions.

The critical moment in the development of a project is the final choice of the work. It is necessary to have in the mind that the two principal functions of a railway tunnel are to resist the surrounding ground and to guarantee a perfectly identified clearance gauge.

Even if the economic situation is unfavourable, safety must be ensured with respect to these two functions. The importance of the work to be done is modulated according to the classification of the lines. On lines with heavy traffic, the constraints of railway operation are such that it is recommended that the structure is treated in a complete way. On secondary lines, it is possible, if the situation allows, to proceed by sections spread out in the time and by the nature of the work.

2.5 - Management of a number of structures

In the maintenance policy, the whole of the elements described in point 2.4 - page 9, have to be taken into account, on the basis of the information that the Infrastructure Manager has to give.

2.5.1 - Principle

The management of a number of structures is based, as mentioned above, on the competences of the people involved: inspectors, engineers and managers. Nevertheless to help them, tools have to be placed at their disposal, such as geographical information systems (location of the structures, description of the damage, etc.) incorporating indicators (factors and evolution indexes, priority of these elements, etc.).

The logic of the process must be put into a policy of global maintenance resulting from a corporate discussion at all levels.

The management of a number of old structures has three principal objectives which are:

- to ensure a given serviceability level,
- to guarantee the safety of the customer, of the third parties and of the agents,
- to preserve the property in the long term.

To do this, it is necessary to identify and to know the property, to appreciate the state, to make diagnosis, to carry out, if necessary, work and to allocate priorities.

The importance of the line and the certain or possible consequences of carrying out the work also have to be taken into account.

A common strategy for the financial, commercial, operating and technical departments can be established starting from a theoretical analysis which makes it possible to optimize the authorized resources in accordance with the desired performance level.

2.5.2 - Theoretical elements of a management processing

For an isolated structure

This approach calls up two principal concepts which are:

- the life span,
- the commercial value of the structure (when built or at the present time).

The lifespan can be probable, residual, theoretical or economic. Generally it is the two last concepts that are taken into account:

- theoretical for an effective utilization period expected when built,
- economic for a utilization period desired after it has been built.

The commercial value is expressed in the renewal value or in the residual value. The latter represents the cost of the renewal of a structure taking into account its actual state, whereas the renewal value represents the actual cost of an identical construction. This results in Fig. 5.

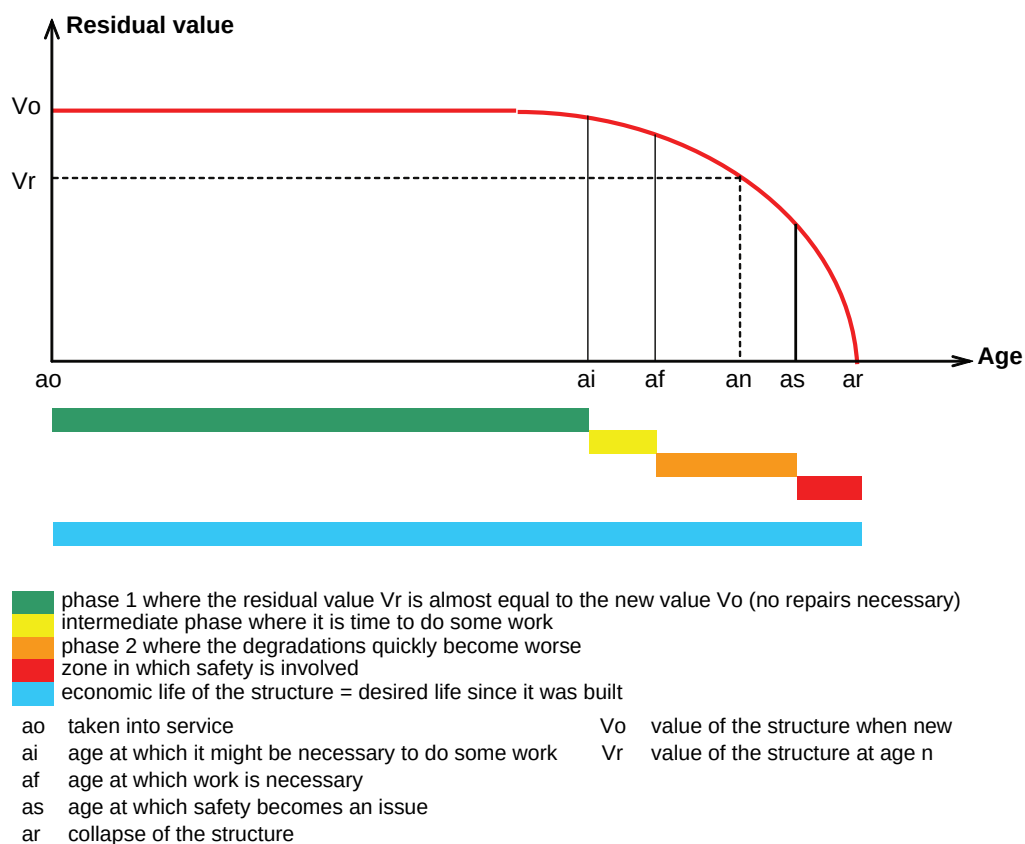
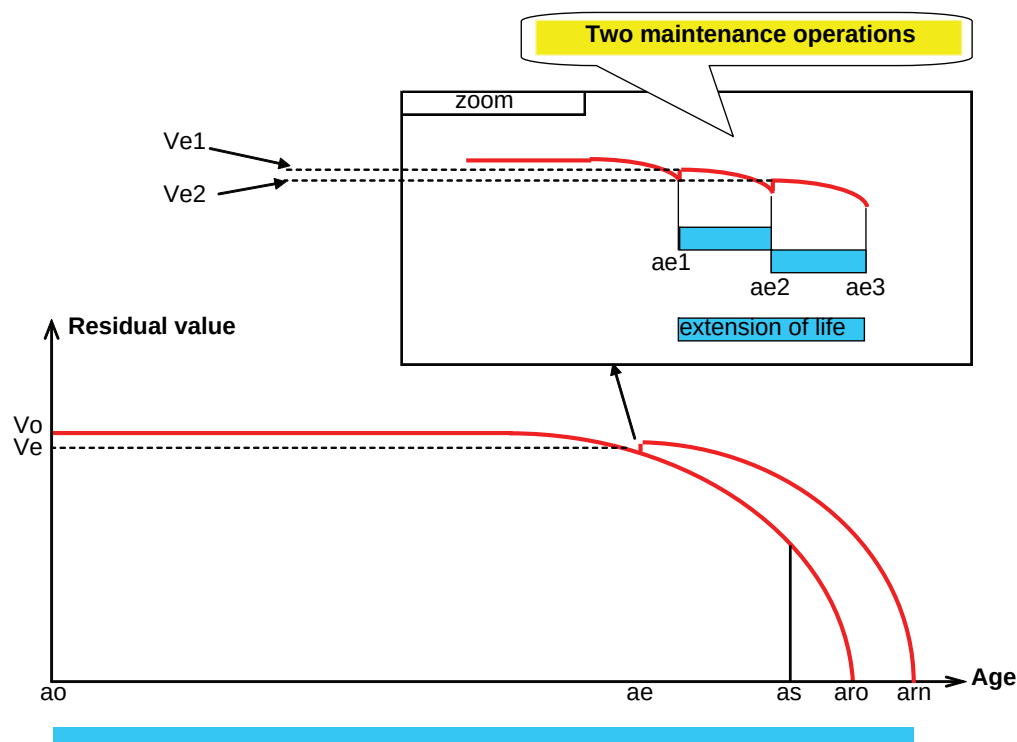


Fig. 5 - Shape of the residual value depending on the age

- Effect of maintenance

Undertaken in phase 1, it has the effect of significantly delaying at low cost, the appearance of important degradations; this can be seen in Fig. 6.

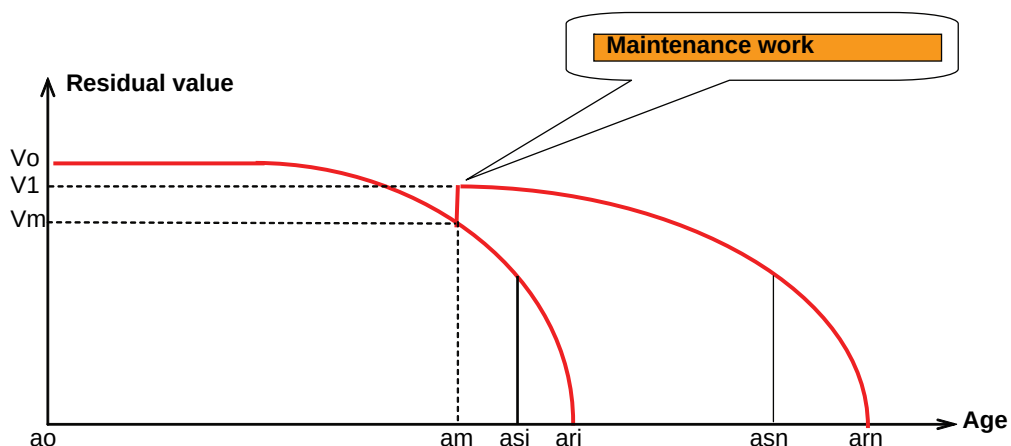


- New life after the accumulated maintenance operations
- V_0 Value of the structure when new
- V_e Value at the age when the maintenance work was done = value close to the new value
- V_{e1} New residual value after the first maintenance work was completed
- V_{e2} New residual value after the second maintenance work was completed
- a_e age of the structure at the moment when the maintenance work was done
- a_{ro} age at which collapse was initially forecast
- a_{rn} new age at collapse after all the maintenance work

Fig. 6 - Effect of maintenance work on the age/value curve

- Effect of a repair

Undertaken in phase 2, it has the effect of restoring the structure to a residual value V_1 close to its renewal value V_0 ; this can be seen in Fig. 7.



■ New life after repair work has been carried out

V_0 Value of the structure when new

V_1 New value of the structure after repair = value close to the initial value when new

V_m Residual value before the repair

a_{ri} age of collapse initially

a_{rn} new age of the collapse after the repair

a_m age of the structure at the time of the repair undertaken during period ■

a_{si} start of the critical period after repair

a_{sn} new start of the critical period after repair

Fig. 7 - Effect of a repair on the value/age curve

For a collection of structures

On main lines, the optimization of the maintenance consists in searching for a regular distribution of the state in terms of geographical distance between two structures to be maintained (i.e. a sufficient distance between them to preserve the normal operation of the line).

On secondary lines, the optimization consists in searching for a regular distribution of the state, but in terms of timescale, in order to treat groups of structures (if necessary by closing the line temporarily).

2.6 - Structure files

Each tunnel should have its own file which must comprise a certain amount of information that aims to identify it and to make possible the inspections under the best conditions.

- the descriptive file shall give details of:
 - the situation
 - the general description
 - the history from the construction to the most recent maintenance, repair, modification or improvement
 - the inventory of the inspections, and investigations
- the record of damage, where all the anomalies or damage are recorded. This is a fundamental document,
- the archived drawings,
- the correspondence on the structure,
- the parts relating to the different work carried out,
- the geometrical recordings.

These topics are developed in point [3.2.1 - page 20](#).

2.7 - Particulars of work to be done in tunnels

The work to be undertaken in tunnels is varied in nature and has very different costs depending on the problems met. It always generates expensive procedures and many constraints.

They are not necessarily related to damage. They can also be work done with the aim of producing an increase in the value of the structure, called here "improvement of the performance".

2.7.1 - Particulars related to the tunnel configuration

The work done in tunnels (inspections, investigations, work, etc.), is very different from the work done on other structures because of the following difficulties:

- Access difficulties; access is only possible through the tunnel entrances and movement through the tunnel is done under bad lighting conditions.
- The limited space available related to the geometrical characteristics of the lining. This element like the preceding one has an effect on the tunnel ventilation.
- Limitation of the available time because of the train service, which has to be mentioned in the majority of cases and also in a very restricted space (impossible to have a temporary deviation, etc.).
- Difficulty of acquiring the information necessary for the diagnosis, in particular that concerning the ground and its interaction with the structure.